Evaluating Multiple Stressors in Loggerhead Sea Turtles: Developing: A Two-Sex Spatially Explicit Model.

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Project Goal. Our overall goal remains unchanged. We are collecting data and developing a model to integrate the effects of multiple stressors into population models as a way of evaluating contemporary management alternatives for species conservation. We are studying spatially- and temporally-specific risks at the species, population and subpopulation level using the NW Atlantic loggerhead population. Our Hypothesis: North Atlantic loggerhead sea turtle (*Caretta caretta* L.) populations respond to the integrated effects of multiple environmental stressors that differentially affect different age classes, sexes, and subpopulations. We anticipate that the stressors also vary in magnitude depending upon the spatial habitat in which they occur. Management alternatives frequently only address a particular life stage, sex, habitat or spatial location, so assessment of the integrated population-level response and consideration of management tradeoffs require a new generation of population models. Our approach to wildlife risk assessment for migratory, long-lived species may subsequently be extended to other protected species.

Work Status. This project was initiated on Nov 15, 2001 when funds arrived at FAU. In year two we initiated work on the model, the predation risks at the different beach sites and, and began collection of sex ratio data at the northern and southern sites to assess unexpected results in 2002. We continue to work with individual site managers to clarify and add metadata to mark and recapture records and well as hatching production estimate. We are continuing ongoing QA and QC.

Data Collections. We completed collection of sex ratio data for the 2002 year class and are collecting a second year of data on sex ratios to begin to assess whether our 2002 results might be typical. We predicted a sex ratio that was strongly skewed toward females based on previous studies – perhaps as high as 1♂:9♀ in the south and 3♂:2♀ in the North. The 2002 year class has a sample sex ratio of 3♂:7♀ south and 1♂:3♀ in the north. These sex ratios are real and well supported by both anatomical verification and discriminate function analyses.

Weather, in the form of tropical depressions, a hurricane, and an unusual cold water upwelling off Florida's east coast played major roles affecting loggerhead recruitment in the 2003 season. These weather and oceanographic events also affected our data collections and affecting realized sex ratios. Weather and sea state were so severe at the northern sites nest often did not hatch and personnel were unable to track turtles leaving the beaches—the assay used to adjust reassess hatchling survivorship the fertility value in the model. As a result no data on predation risks were collected at the northern sites.

Hatchling Survivorship and Predation Risk

Loggerhead hatchlings were followed as they migrated away from nesting beaches to determine the probable recruitment for each site. Hatchling success was based on if the turtles were lost to predators or not. If visual identification of the predators was possible, the type of predator taking the hatchlings was recorded (Table 1).

Table 1. Summary of sea turtle hatchling predator data by site and subseason.

Hatchling SubSeason	**Boca Raton Predators**	**Sanibel Predators**
Early	1 unknown	N/A
Middle	No predation	1 Snook *Centropomus undecimalis*
Late	9 Bluefish *Pomatomus saltatrix* 2 Tarpon (*Megalops atlanticus)* 1 Barracuda (*Sphyraena barracuda)* 2 unknown	1 Snook or Jack (*Caranx spp.)*

Hatchlings were followed from two beach sites, Boca Raton (N26°22′01.5″ W080°04′05.0″) on the east coast and Sanibel (N26°25′19.0″ W082°04′49.0″) on the west coast of South Florida. The predation rates were compared by early, middle and late season at each of the sites, and seasons were compared across sites. Based on previous studies, predation rates of 5% were expected (Stewart and Wyneken 2003). There was no significant difference between the observed and the expected predation rates, except for the predation observed in Boca Raton during the late season (Fisher exact probability test, $p = 0.0005$). The level of predation observed in Boca Raton during the late season differed significantly from the Boca early season (Fisher exact probability test, $p = 0.031$), Boca mid season (Fisher exact probability test, $p = 0.002$) and the Sanibel late season (Fisher exact probability test, $p = 0.031$). Table 2 summarizes the percent predation at the two sites, by season.

No information was collected in Sanibel during the early season due to on-site personnel being unable to locate clutches and collect hatchlings. Sampling at Sanibel was reduced to just a few days by heavy rain and unusually high tides throughout the season. Two large storms, (June 28, and another lasting September 4- 7, 2003) resulted in high seas and the loss of nests to wash out or inundation with water.

Our goal was to collect hatchling survivorship data at both Northern and Southern sites. However this was not possible. In addition to heavy and prolonged rain and number of storms that hit the midAtlantic coastline and the Gulf coast of Florida, the other Southern sites chosen for the east coast, Juno Beach, Hutchinson Island and Melbourne became unusable when prolonged coldwater upwellings occurred. An anomalous wind pattern from the southwest caused an intermittent cold water upwelling from late June into September. Water temperatures were recorded as low as 54 °F. The upwelling fish-kills, reduced fish feeding where they lived, and caused many cold-stunned hatchlings to be washed back onto shore. Hatchlings released at those sites soon ceased to swim. After several different attempts, we concentrated on sites that were likely to maximize informative data.

Table 2. Summary of Hatchling survivorship assessment in the nearshore environment.

	Early Season	Mid Season	Late Season	Total
Boca Raton	**5.0%**	**0.0%**	**26.9%**	**15.5%**
Sanibel		**4.8%**	**5.0%**	**4.9%**
		Depredated	**Alive**	
	Boca Early	**1**	**19**	
	Boca Mid	**0**	**25**	
	Boca Late	**14**	**38**	
	Sanibel Mid	**1**	**20**	
	Sanibel Late	**1**	**19**	

Model Development. Population modeling

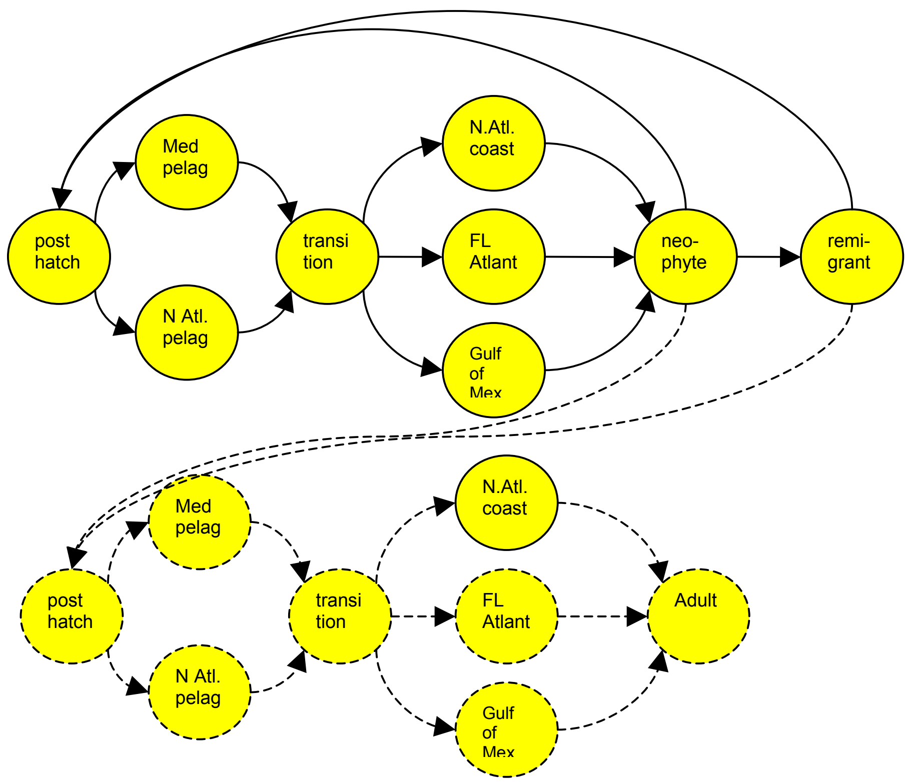
The data generated by the sex ratio analyses form the key component of new population models to assess the importance of multiple stressors on loggerhead turtle populations. The PIs met and discussed alternative model structures and approaches for analysis with Dr. Selina Heppell of Oregon State University (under contract with the SE Fisheries Science Center of NOAA Fisheries). The models build on those developed by Melissa Snover, Larry Crowder and Sheryan Epperly (NMFS 2002) and discussed in Heppell et al. (2003). They will include both sexes and population structure in the form of stages that occur in different habitats. The goal of the modeling exercise is to determine the relative contributions of Northern and Southern stocks to population growth as a whole and to determine how stressors in particular environments (beaches, open sea, nearshore) may affect population dynamics.

Model 1: Deterministic with fixed stage durations

This model utilizes 4 age-structured submodels: Northern males, Northern Females, Southern Males, Southern Females. The 4 submodels run in parallel, allowing calculation of the proportion of each stock and sex in each stage. Stages represent habitats and/or life stages, and most have multiple age classes in a stage. For this version, stage durations are fixed and the models are deterministic. Reproduction is dependent on the proportion of males in the population.

Figure 1 shows the conceptual model with the 4 components. Each circle represents a stage with a different number of age classes. Arrows represent reproduction or transition probabilities; dashed lines are males, solid lines are females. The number of years in a stage and survival rates can be specific for male vs. female, Northern vs. Southern, although we are unlikely to have data to support differential mortality. Reproduction occurs only in the two female submodels, but can be a function of the number of males from the North and South. Parameterization of these relatively simple models will require substantial effort. Data collected from this EPA study will go into the measures of fertility: the number of male and female hatchlings produced in the North and South each year.

Figure 1. Conceptual two sex population model. Abbreviations and definitions. posthatch: posthatchlings; Med. pelag: Mediterranean pelagic stage; N. Alt. pelag: North Atlantic pelagic stage; transition: transitional stages that migrate between coast and pelagic habitats; N. Atl. Coast: Northern Atlantic coastal (feeding zones) stages; FL Coastal: Florida coastal feeding zone stages; Golf of Mex.: Juveniles in feeding zones of Gulf of Mexico; neophyte: 1st time breeder female; remigrant: female that breeds and nests again after its first breeding season; Adult: adult male that may or may not breed.



Post-hatchling survival will also be subpopulation specific, if data become available in 2004. Growth rates (= stage durations) and survival rates will come from the literature and from in-water survey data obtained from cooperators in Florida and North Carolina. The proportion of turtles migrating to alternative locations (pelagic turtles to the Mediterranean and benthic turtles to the North Atlantic, Florida and Gulf of Mexico) is a difficult problem because there is not enough tagging information to determine the probability of settling in one location vs. another. However, if we make the assumption of equal at-sea survival rates for juvenile males and females from the North and South, we may be able to use genetic and sex ratio information from surveys in each location to reconstruct those probabilities.

Sensitivity analysis will be critical for this model to (a) assess the importance of uncertainty in unknown parameters and (b) calculate the relative contribution of each location-specific survival rate to overall population growth (elasticity analysis- Caswell 2001). Dr. Heppell recommends a combination of individual parameter sensitivity assessment and Monte Carlo approaches to generate distributions of model outputs.

Model 2: Adding variable stage duration to Model 1.

Individual variability in growth results in a distribution of age-at-size for sea turtles. Model 1 will be modified to include variable stage lengths for pelagic and benthic immature turtles, based on data from the literature and in-water mark-recapture studies. The purpose of this exercise will be to determine the importance of variability in growth to the model outputs.

Future models: Simulation modeling or individual-based approaches

Future models could add stochasticity to Model 1 or 2 and/or develop an individual-based model. The difficulty with these approaches is the need for annual variability and co-variance for each parameter. These alternatives may be desirable if the deterministic models are insufficient to address management questions.

Loggerhead Growth Results.
Initial hatchling size (length, width, depth, and weight) were compared among hatchlings from the northern and southern subpopulations. Turtles were also compared within the southern subpopulation from east and west coasts of Florida. Turtles from northern subpopulation were larger in every measure during every phase of the nesting season than the southern subpopulations hatchlings. We found no significant differences in initial size between turtles from Southeast and Southwest Florida.

-Initial size decreased as latitude decreased, demonstrating a size gradient down the coast.
-Containment in individual rearing baskets did not influence hatchling growth rates for the first 3 months.

Because of slight differences in rearing facilities and water temperatures at different part of the season we segregated so that we compared turtles using the first 5 weeks, 7 weeks or 9 weeks of growth data as described below.
<u>5 wk and 9 wk comparisons of Southeastern Florida hatchling Growth Rates.</u>
Turtles deposited during the earliest phase of the nesting season grew faster than those from later phases of the season did. Significant downward trend in the linear growth rates (SCL, SCW, and BD) as the season progressed. We found no significant differences in hatchling growth rates among beaches

<u>Growth rates in the northern subpopulation for 7 wk</u>
Weight gain and SCL growth in Early season was more rapid than Middle and Late season hatchlings. Beach of origin influenced weight gain, SCW and BD growth rates in

northern sample. Cape Lookout, North Carolina produced hatchlings that grew significantly faster than those from other beaches.

Northern *vs*. southern subpopulation comparisons:
Although not compared statistically, some general observations were made. Daily growth rates were greater for all measures in the northern turtles at every beach and across all phases of the nesting season. However, these turtles were larger initially and proportional increases were very similar between the 2 subpopulations. We will look further at these trends.

These data will be used in the model to modify stage durations. The ability to succeed in multiple habitats, each with stage-specific risks of mortality, often involves maximizing physiological and morphological performance to minimize mortality risks. The factors that affect growth represent a balance between resource acquisition and allocation and the energetic costs associated with each. Larger or stronger hatchlings may be more likely to escape predation than smaller turtles.

Turtles deposited during the earliest phase of the nesting season grew faster than those from later phases of the season, suggesting potential advantages to the maternal resource allocation and/or incubation environment early in the season. It is also likely that water temperature fluctuations influence hatchling growth rates even within a narrow range. In addition to maternal influences, environmental factors play a role in initial size and growth potential in sea turtle hatchlings. Studies have shown that eggs in a drier environment hatched sooner and produced smaller hatchlings than those in moister environments, where temperature correlated negatively and % water content correlated positively with hatchling length (Morris et al. 1983, Packard and Packard 1984, Reece et al. 2002, Glen et al. 2003). Supporting this relationship between temperature and initial size, the hatchlings with the largest initial size were found in North Carolina (coolest nest temperatures) and the smallest in Florida (warmest nest temperatures), as predicted. The nesting beach influenced initial hatchling size in the northern subpopulation but not in southeastern Florida.

With a better understanding of growth patterns among populations, we can further refine vital rates (time in each life stage, spatially and temporally explicit stage parameters) Differences in initial size and growth potential could influence early stage survivorship as a function of size-based predation. Based upon these data, hatchlings from the southern-most and northern-most portions of the nesting range, as well as from different phases of the nesting season, perhaps should be considered separately when predicting survivorship and total demographic contribution in future population models.

Personnel Changes. Melissa Snover accepted a post-doctoral position at Univ. California-Santa Cruz and left the project in June 2002. She maintains an advisory role with the project. We gained the assistance of our colleague, Dr. Selina Heppell, to work with us on model development. Dr. Heppell is not paid by this project but is working with our data to assist us in model development.

Expenses. Expenses to-date have fully consumed all budgeted funds. Expenses have exceeded budgeted amounts because the costs to successfully rear turtles were increased by unanticipated conditions and restrictions imposed by the regulatory (permitting) agencies that had an impact in year 1. The result was greater set-up, labor, veterinary, and food costs at FAU, Mote Marine Lab, and Duke Marine Lab. In Year 2, we incurred the expected costs plus additional cost associated with our attempts to work around weather events and collect predation risk data.

Plans the coming year. We will continue to update and partition the mortality associated with several well-documented environmental stressors (including photopollution, beach renourishment, boat interactions, and fishery interactions). Additionally we will expand our new comprehensive data to describe the sex ratios of hatchlings throughout the entire season from multiple beaches encompassing both subpopulations. And, we will finish documenting hatchling survivorship by following migration past predator-rich nearshore waters for several southern subpopulation beaches where we have partial data. We will meet and determining how to best scale sex ratios for each subpopulation and we will continue to identify develop parameters for the model.

Selected Publications

Heppell, S.S., L.B. Crowder, D.T. Crouse, S.P. Epperly and N.B. Frazer. 2003. Population models of Atlantic loggerheads: Past, present, and future. Pp.255-273, IN: A.B. Bolton and B.E. Witherington (eds.) Loggerhead Sea Turtles. Smithsonian Institution Press, Washington, DC.

Crowder, L.B. 2003. Reversing the decline of sea turtles: Insights from life-history population models. Pp. 93-98. In: N. Valette-Silver and D. Scavia (eds.) Ecological Forecasting: New tools for coastal and marine ecosystem management, NOAA Technical Memorandum NOS NCCOS 1.

Wyneken. J, M. M. Garner, and C. A. Harms. 2003. Tracking Natural Sex Ratios and Posthatchling Gonadal Development in Posthatchling Loggerhead Sea Turtles (*Caretta caretta*) Using Laparoscopy, Gross Morphology, and Histology. Proceedings of the Annual ARAV Conference.

Theses

Stokes, Lesley 2003. A Seasonal and Latitudinal Assessment of Early Growth Rates in Northern and Southeastern Loggerhead Sea Turtles (*Caretta caretta* L.) Masters Thesis. Florida Atlantic University. Boca Raton, Florida.

Presentations

Wyneken, J. Tracking natural sex ratios and posthatchling gonadal development in posthatchling loggerhead sea turtles *(Caretta caretta)* using laparoscopy, gross morphology, and histology. Association of Reptilian and Amphibian Veterinarians/ Association of Zoo Veterinarians Conference. October 2003.

Wyneken, J. Atlantic Loggerhead Sea Turtles from North Carolina to Florida: Historical ideas & surprising sex ratios Florida Sea Turtle Permit Holders Meeting, (Orlando, Florida)